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Environmental Effects of Oil Shale Mining and Processing. Part II: The Aquatic Macroinvertebrates of the Piceance Basin, Colorado, Prior to Oil Shale Processing

Colorado State Univ., Fort Collins. Natural Resource Ecology Lab

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Part II: The Aquatic Macroinvertebrates of the Piceance Basin, Colorado, Prior to Oil Shale Processing

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FOREWORD

This report contains the data from a preoperational biological survey of invertebrates in Piceance Creek, Colorado where oil shale development is anticipated. It is one of a series of reports all intended to better describe energy development impacts on aquatic environments in the West. The value of this report will increase in future years because it will become a reference point in time by which changes in Piceance Creek will be judged.

Donald I. Mount, Ph.D.
Director
Environmental Research Laboratory-Duluth

ABSTRACT

A study was conducted at sampling sites on four streams in the Piceance Basin of northwestern Colorado to acquire data on benthic macroinvertebrate communities prior to commencement of oil shale mining and processing activities. Piceance Creek, the major stream studied, exhibited considerable longitudinal variation in environmental conditions. Sodium, sulfate, chloride, and total dissolved solids increased greatly in the downstream direction. The temperature range, turbidity, severity of winter ice conditions, and effects of grazing and irrigation activities also increased downstream. Downstream reductions in density, biomass and diversity, and altered macroinvertebrate species composition were associated with the longitudinal changes in environmental parameters. The fauna of upstream areas of Piceance Creek and its tributaries was composed of primarily winter species (those that complete their life cycle from fall to spring), whereas the fauna of downstream reaches of Piceance Creek was composed almost entirely of summer species. Effects of oil shale mining and processing activities on aquatic biota will depend upon the type of mining employed, the extent of surface and subsurface disturbance, the success of pollution controls, points of pollution entry, and extent of water depletion. Present environmental conditions and macroinvertebrate communities of lower reaches of Piceance Creek may be indicative of the potential effect of future impacts at upstream locations.

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SECTION I

INTRODUCTION

The Piceance Creek Basin is a large area of land in northwestern Colorado underlain by rocks of the Green River Formation, the primary source of oil shale in the United States. Although Colorado has the smallest geographical area of oil shale, its deposits are the richest and best known. High grade deposits total 400 to 600 billion barrels of oil (U.S. Department of the Interior, 1973).

The present study of the benthic macroinvertebrates of Piceance Basin streams was conducted year-round from August 1975 through April 1977. The objective of this research was to gain an understanding of the structure and function of the macroinvertebrate community and its relationship to the physical and chemical environment prior to oil shale extraction and processing activities.

Previous studies of the macroinvertebrate fauna of Piceance Creek include Everhart and May (1973), Pennak (1974), Woodling and Kendall (1974), and consultants to Shell Oil Company (C-b Shale Oil Project, 1976). No previous studies have been conducted on Black Sulphur Creek.

SECTION II

CONCLUSIONS

1. Piceance Creek exhibits considerable longitudinal variation in environmental conditions. The harshness of physical and chemical conditions increases downstream. These downstream changes are caused naturally by the geochemistry of the basin and are enhanced by effects of current grazing and irrigation practices.

2. Macroinvertebrate standing crop and diversity decrease downstream. The species composition of the macroinvertebrate community also varies longitudinally. Winter species predominate in upstream areas of Piceance Creek and in most tributaries, whereas downstream reaches are comprised primarily of summer species.

3. Although Piceance Creek is, in general, a relatively harsh aquatic habitat, it is capable of considerable resilience to destructive forces, such as winter ice conditions.

   a. This resiliency is thought to be, at least partially, a result of the ecological role played by entering spring brooks.

   b. Springs in the headwaters and spring-fed tributaries provide approximately 80% of the base flow of Piceance Creek (Weeks et al., 1974).

   c. Springs provide water which increases winter temperatures and reduces summer temperatures in Piceance Creek. Springs also supply water of low turbidity.

   d. Preliminary evidence also indicates that spring-fed reaches provide a source of benthic organisms which allows maintenance of certain species populations in Piceance Creek.

4. Alteration of the quality or quantity of ground water, or other modification of the spring brook habitats, would be expected to result in changes in the macroinvertebrate communities of Piceance Creek.

5. This study was devised and conducted based upon the TOSCO II process which was the intended recovery method at that time. The development plan has since been revised; present plans are to utilize a modified in situ recovery method for Tract C-b. The conclusions of this paper are based upon the TOSCO II process and would be somewhat different for an in situ method.

SECTION III

RECOMMENDATIONS

Upon commencement of mining activities, chemical and biological sampling should resume at sites PC-2, PC-3, PC-4, WC-1, and SG-1. Additional stations should be established on Willow Creek and Stewart Gulch above drainage from Tract C-b, and at the sources of springs adjacent to Tract C-b. Biological sampling of macroinvertebrates should document any changes in species composition, standing crop, or community structure associated with any changes in the quality or quantity of water resulting from mining activities.

SECTION IV

DESCRIPTION OF STUDY AREA

The Piceance Basin in northwestern Colorado is part of the northern cool desert. Annual precipitation ranges from 30 to 50 cm. Summer air temperatures may exceed 40°C and winter temperatures may be as low as -40°C (Weeks et al., 1974). Big sagebrush (*Artemisia tridentata*) is the dominant plant in valleys and on slopes, forming associations with either grasses and forbs or other shrubs. On the ridges a pinyon (*Pinus edulis*)-juniper (*Juniperus osteosperma* and *J. scopulorum*) woodland dominates. Plant coverage for the basin as a whole averages only 25% of the land's surface. Hay is grown on irrigated land in the stream valleys, and some pinyon-juniper woodland has been cleared by ranchers to promote grassland for grazing (U.S. Department of the Interior, 1973). Elevations near potential sites of oil shale extraction range from 2,000 to 2,250 m with local reliefs of over 100 m.

Figure 1 shows Piceance Creek and its tributaries, many of which are intermittent streams. Discharge records for Piceance Creek (Table 1) show large seasonal and yearly fluctuations. These fluctuations are due primarily to variations in precipitation, but are also caused, to a certain extent, by diversions for irrigation (about 5,500 acres, or 22.3 km^2, are irrigated with water from Piceance Creek) (U.S. Geological Survey, 1974).

Water quality data for Piceance Creek are shown in Tables 2 and 3. The concentrations of sodium, sulfate, and chloride increase greatly between the headwaters and the mouth. These increases, and the increases in total dissolved solids in general, are apparently caused by groundwater inflows from the leached zone of the Parachute Creek Member of the Green River Formation. The Parachute Creek Member, in addition to containing the richest oil shale, contains deposits of soluble alkaline and saline minerals, principally nahcolite ($NaHCO_3$), halite (NaCl), and gypsum ($CaSO_4 \cdot 2H_2O$). These mineral deposits reach their greatest concentration in the lower reaches of Piceance Creek. Below Ryan Gulch, beds of these minerals are up to 1,000 feet thick. Two springs over these beds that empty into Piceance Creek (springs S-2 and S-6, see Figure 1 and Table 2) had total dissolved solids concentrations of 6,120 and 22,100 mg/liter, while two springs above Ryan Gulch (springs S-5 and S-4) had concentrations of 703 and 1,220 mg/liter, respectively (Weeks and Welder, 1974).

Increases in dissolved solids concentrations in Piceance Creek may also be partially the result of irrigation activities. Diversions would decrease the amount of higher quality flows from upstream areas, and return flows would carry higher concentrations of dissolved solids, thus adding to the load already present.

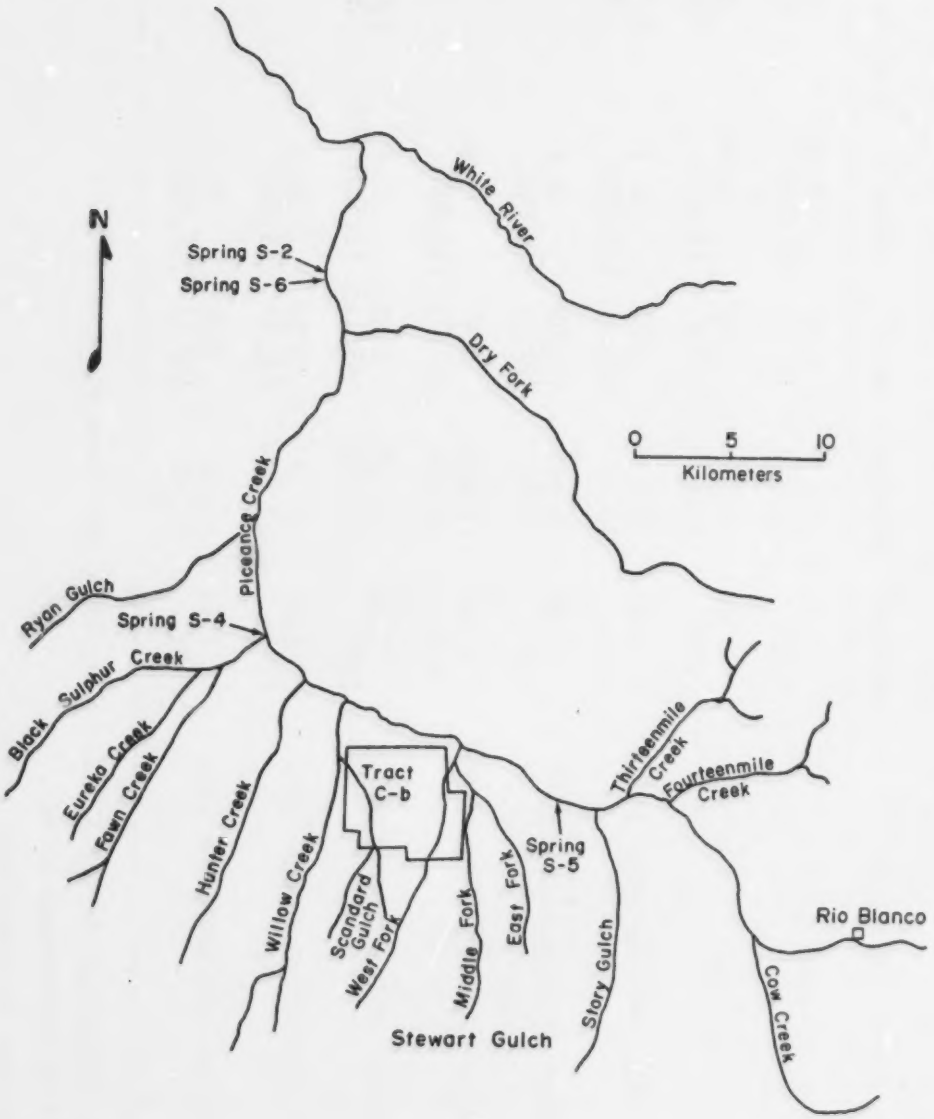

Figure 1. Piceance Creek Basin, Colorado.

TABLE 1. DISCHARGE RECORDS FOR PICEANCE CREEK, COLORADO.[a/]

Location	Period of record	Maximum[b/]	Minimum[b/]	Mean[b/]	Total[c/]	Drainage area[d/]
340 m above Stewart Gulch	April-September 1974	4.3 (152)	0.1 (3.7)	0.28 (9.8)	3.66 (2,978)	458 (177)
0.6 km above Hunter Creek	April-September 1974	4.4 (155)	0.13 (4.6)	0.31 (10.8)	4.08 (3,320)	800 (309)
12 m down from Ryan Gulch	October 1972-September 1973	2.83 (100)	0.1 (3.7)	0.82 (29.1)	14.9 (12,100)	1,256 (485)
	October 1973-September 1974	1.62 (57)	0.085 (3.0)	0.77 (27.3)	24.4 (19,800)	
	October 1964-September 1974[e/]	11.0 (400)	0.006 (0.21)	0.5 (17.7)	15.8 (12,800)	
At mouth	October 1971-September 1972	2.83 (100)	0.024 (0.84)	0.37 (13.1)	11.7 (9,520)	1,632 (630)
	October 1972-September 1973	3.26 (115)	0.10 (3.6)	0.92 (32.6)	29.0 (23,580)	
	October 1973-September 1974	2.44 (86)	0.16 (5.8)	0.97 (34.2)	30.4 (24,730)	

[a/] Records from U.S. Geological Survey (1972, 1973a, 1974) and Ficke et al. (1974).

[b/] Data in m^3/s (cfs in parentheses below).

[c/] Data in hm^3 (acre-feet in parentheses below).

[d/] Data in km^2 ($mile^2$ in parentheses below).

[e/] Total discharge given as a yearly average over period of record.

TABLE 2. WATER QUALITY DATA FOR SELECTED STREAM LOCATIONS IN THE PICEANCE CREEK BASIN, COLORADO AND FOR SPENT SHALE LEACHATE (RANGE OF VALUES IN MG/LITER EXCEPT AS NOTED)

Chemical constituents	Spent shale[a] leachate	Piceance Creek[c] at mouth	Piceance Creek[b] headwaters	Piceance Creek[d] Springs
Ca^{++}	3,150	34-77	49.9-110.0	18-7.9
Mg^{++}	4,720	74-110	27.7-60.6	33-64
Na^{+}	35,000	200-810	7.8-235.0	2,300-9,200
K^{+}	44	3.0-6.2	0.6-10.0	8.5-5.7
$SO_4^{=}$	90,000	300-580	65.6-283.0	180-110
Cl^{-}	3,080	16-120	6.8-13.0	780-1,600
HCO_3^{-}	--	701-1,790	--	4,060-22,500
NO_3^{-}	7.4	0.01-0.79	0.5-3.8	1.4-0.88
$PO_4^{=}$	1.4	0.03-0.08	--	0.84-1.8
Total alkalinity	--	575-1,500	270-500	4,540-18,500
pH	--	7.9-8.7	7.6-8.4	--
Temperature, °C	--	0-21	0-15	--
Dissolved O_2	--	6.2-11.4	6.5-11.2	--
Dissolved organic matter	--	169.9-237.0	90.5-108.4	--
Suspended organic matter	--	4.6-22.2	0.8-2.4	--
Suspended inorganic matter	--	4.6-134.2	2.7-10.4	--
Total dissolved solids	76,000	1,153-3,159	377-728	6,120-22,100

[a] From Ward et al. (1971). Values are the potential maximums.

[b] From Everhart and May (1973) and Pennak (1974).

[c] From U.S. Geological Survey (1973b) and Pennak (1974).

[d] From Weeks and Welder (1974). Spring S-6 cited first, then Spring S-2. See text for comments.

TABLE 3. SIGNIFICANT TRACE ELEMENTS AND IONS IN PICEANCE CREEK AND SPENT SHALE LEACHATE IN RELATION TO WATER QUALITY CRITERIA FOR AQUATIC LIFE (VALUES IN MG/LITER)

Ions	Spent shale[a] leachate	Piceance Creek[b]	Piceance Creek[c] Springs S-2 and S-6	Water quality criteria for[d] aquatic life
Trace elements				
Aluminum (Al^{+3})	0.10	--	0.02-0.05	0.10
Barium (Ba^{+2})	0.16	--	0.0-6.3	5.0
Fluoride (F^{-})	0.14	0.7-7.0	0.4-28.0	1.5
Zinc (Zn^{+2})	0.10	--	--	0.10
Anions				
Chloride (Cl^{-})	Up to 3,080	6.8-120.0	780-1,600	Ambient levels
Sulfate (SO_4^{-2})	Up to 90,000	65-580	110-180	Ambient levels
Total dissolved solids	Up to 76,000	377-3,159	6,120-22,100	Ambient levels

[a] From Ward et al. (1971).

[b] From U.S. Geological Survey (1973b) and Everhart and May (1973).

[c] From Weeks and Welder (1974). See text for comments.

[d] From National Academy of Sciences, National Academy of Engineering (1973) and McKee and Wolf (1963).

Piceance Creek, the largest stream studied, begins in the White River National Forest at an elevation of 2440 m and flows 80 km before entering the White River at an elevation of 1738 m. It has a permanent flow due to incoming groundwater from numerous surface springs and spring-fed tributaries, but certain portions are intermittent, particularly that part between PC-1 and PC-2 (Figure 2). The streambed is composed of sedimentary rocks (shales, marlstones, and sandstones) that are readily decomposed by physical and chemical processes. Riparian vegetation consists of sagebrush and other shrub communities, hay meadows, and occasional willows that do not form a complete canopy over the stream. The stream is affected by cattle pastured in riparian meadows during winter, and irrigation withdrawals and return flows from April to October.

Black Sulphur Creek, the largest tributary of Piceance Creek, is about 32 km long and enters Piceance Creek at an elevation of 1890 m. At BSC-1 it flows through a hay meadow with some willows. The substratum is similar to upper Piceance Creek, and this site is affected by grazing and irrigation activities. Table 4 summarizes the physical and chemical characteristics of the Piceance and Black Sulphur Creeks sampling sites for the first year of study (August 1975 to July 1976). Table 5 summarizes similar data for the middle Piceance sites during the second year (August 1976 to April 1977).

PC-1 possesses several unique characteristics as a result of its spring-fed nature. Most of the base flow originates from several bankside springs that enter 1 km above the sampling site. These springs create relatively constant temperatures and chemical conditions. Discharge is also relatively constant, except during the spring (March to May) when runoff increases flows and scours the streambed. Unlike other Piceance sites, PC-1 is not appreciably affected by grazing and irrigation activities.

The middle Piceance Creek sites show increases in dissolved solids, turbidity, and temperature range compared to PC-1. Although surface and frazil ice were present in the winter, the proximity of these sites to surface springs and spring-fed tributaries (Stewart Gulch and Willow Creek) prevented anchor ice formation. This groundwater is also important in preventing high temperatures during the summer. Irrigation withdrawals beginning in early spring reduced runoff, thus lessening streambed scour; withdrawals also created very low flows by late summer (cf. Weeks et al., 1974). The addition of suspended solids, dissolved solids, and plant nutrients by return flows increased siltation, salinity, and growths of filamentous algae. The effects on water quality by these return flows are illustrated by changes occurring at the sampling site located between Stewart Gulch and PC-3. During the winter (November 1975 through February 1976), when no irrigation was occurring, mean concentrations (n=12) of total dissolved solids, total suspended solids, and phosphates were 700 mg/liter, 5 mg/liter, and 0.03 mg/liter, respectively. In June and July 1976 when irrigation was extensive and runoff had essentially ceased, mean concentrations (n=8) were 876 mg/liter, 21 mg/liter, and 0.04 mg/liter, respectively.

Increases in dissolved solids at the middle Piceance sites, compared to PC-1, are also due to higher concentrations in entering groundwater. Soluble minerals (principally nahcolite) associated with richer strata of oil shale

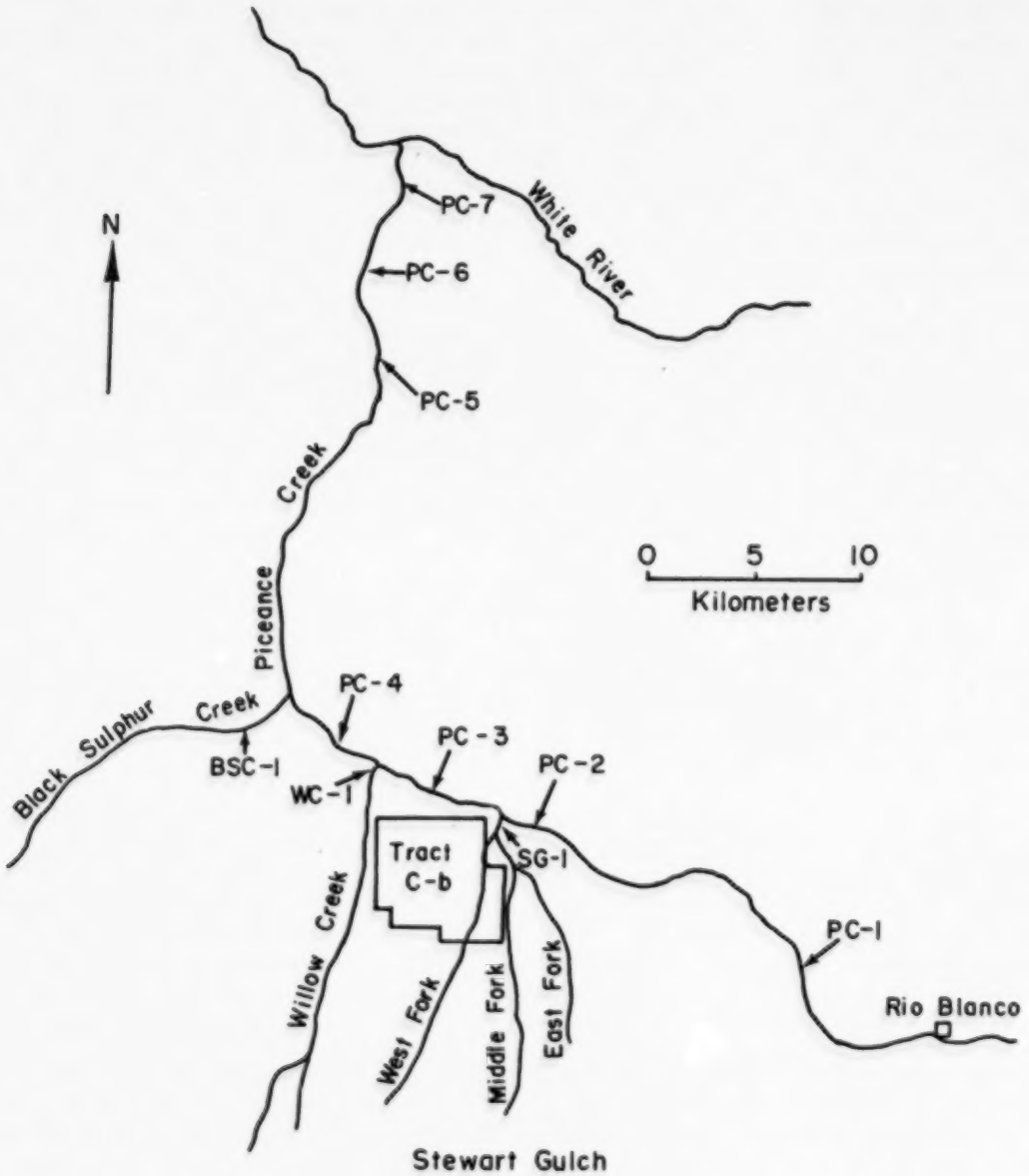

Figure 2. Piceance Creek, Colorado and major tributaries showing sampling locations.

TABLE 4. PHYSICAL AND CHEMICAL CHARACTERISTICS OF PICEANCE CREEK AND BLACK SULPHUR CREEK SAMPLING SITES, AUGUST 1975 TO JULY 1976

Parameter	PC-1	PC-2 to PC-4	PC-5 to PC-7	BSC-1
Total dissolved solids, mg/liter[a]	520	795	1,375	1,115
Total suspended solids, mg/liter[a]	26	34	251	76
Temperature range, °C[b]	3-14	0-21	0-25	2-18
Mean width, m[b]	2.2	3.6	5.1	3.1
Mean depth, cm[b]	12	21	22	15
Substratum[c]	Rubble-gravel	Rubble-gravel	Unstable gravel[d]	Rubble-gravel
Winter ice conditions	No ice	Surface and frazil ice	Surface and anchor ice	Surface ice
Disturbance from cattle (winter)	No	Yes	Yes	Yes
Spring runoff scour	Yes	Not observed	Not observed	Yes
Magnitude of irrigation withdrawals and return flows	Very small	Large	Large	Small

[a] Skogerboe et al., in press (mean values for October 1975 to July 1976).

[b] From field measurements.

[c] General downstream increase in situation.

[d] Except PC-5 (see text).

at tract C-b are leached by groundwater contained in the Uinta Formation aquifer and upper Parachute Creek Member (Green River Formation) aquifer (C-b Shale Oil Project, 1976).

Physical and chemical conditions at the middle Piceance Creek sites during the second year of study were similar to the first year in terms of total dissolved solids, total suspended solids, and temperature range (Tables 4 and 5). Discharge during the second year was at least 25% below first year levels.

The lower Piceance Creek sites have the harshest physical and chemical conditions. These sites are characterized by high dissolved solids concentrations, high turbidities, a wide temperature range, anchor ice during the winter, and an unstable, gravel substratum. The high dissolved solids concentrations are partially the result of irrigation activities; however, they are primarily due to inflows of highly saline groundwater from the lower Parachute Creek Member aquifer, both from small surface springs and interconnections with the alluvial aquifer (Weeks and Welder, 1974; Weeks et al., 1974). The high turbidities are caused by increased discharge combined with smaller sediment particles and, to a lesser extent, by return flows. Since the lower sites are some distance from either large springs or tributaries, the range of temperatures is greater, thus causing high temperatures in the summer and anchor ice in the winter. At PC-5, a small outcropping of bedrock has created a rubble substratum similar to the middle Piceance sites.

Compared to the Piceance Creek sites, Black Sulphur Creek is a composite of physical and chemical characteristics. This is the result of headwater springs, saline groundwater entering from the lower Parachute Creek Member aquifer, and enrichment from a cattle pen about 1 km above the sampling site.

Sampling sites were also located on the other two spring-fed tributaries of Piceance Creek: Stewart Gulch and Willow Creek (Figure 2). Their physical and chemical conditions are generally similar to BSC-1, although total dissolved solids concentrations are lower. Their contribution to the total discharge in Piceance Creek is indicated by the increased discharge at PC-3 and PC-4 compared to PC-2 (Table 5).

TABLE 5. PHYSICAL AND CHEMICAL CHARACTERISTICS OF PICEANCE CREEK, AUGUST 1976 TO APRIL 1977

Parameter	PC-2	PC-3	PC-4R[b]	PC-4P[b]
Total dissolved solids, mg/liter[a]	--	830	867	--
Total suspended solids, mg/liter[a]	--	45	74	--
Temperature range, °C	0-20	0-19	0-21	0-21
Mean width, m	4.0	3.4	3.1	3.3
Mean depth, cm	15	17	21	25
Mean current velocity, m/s	0.36	0.39	0.40	0.29
Mean discharge, m^3/s	0.17	0.18	0.21	0.21

[a] Skogerboe et al., in press (mean values for August 1976 to March 1977). Remaining data from field measurements.

[b] R = Riffle
P = Pool

SECTION V

MATERIALS AND METHODS

Benthic macroinvertebrates were collected monthly at each of the 10 sampling sites during the first year of study (Figure 2). During the second year, sampling was continued in riffle areas at PC-2, PC-3, and PC-4. A pool area at PC-4 was also included.

Quantitative samples were collected in the first year with a standard Surber square-foot bottom sampler (700 μm mesh). In the second year, collections were made with a metal cylinder which enclosed an area of 325 cm^2. Bottom materials were removed, washed, and strained through 700 μm mesh netting, and the water within the cylinder was strained through the same netting. In riffle areas five or more samples were taken in a transect across the stream (three samples in pools). It was necessary to use a cylinder to sample pools since the Surber sampler requires considerable current. Pools have quite different microhabitats which have been often overlooked in stream studies. Sampling devices were compared using an index of precision. Each sample was kept separate to allow statistical analysis of within-site variation and to gain a general understanding of the distribution of particular species. Samples were preserved in the field with 5% formalin and later transferred to 80% ethanol.

Biomass was determined during the first year of study by displacement in a graduated centrifuge tube, assuming a specific gravity of 1.0 (a close approximation). In the second year, the organisms were dried to a constant weight at 60°C and weighed on an analytical balance to the nearest 0.1 mg.

Species diversity and equitability were calculated from formulas in Weber (1973). Techniques used for statistical analyses are discussed in a later section.

Identifications of organisms were based primarily upon Usinger (1956), Edmondson (1959), and Mason (1973). Additional references used for species identifications included Ross (1944, 1956), Allen and Edmunds (1962, 1965), Brinkhurst (1965), Jensen (1966), Gaufin et al. (1966), Nebeker and Gaufin (1967), Brown (1972), Gaufin et al. (1972), Klemm (1972), Kilgore and Allen (1973), and Baumann (1975). Species identifications of immature insects were determined by association with adults collected at the same sampling site. Adults were collected throughout the study period using sweep nets and light traps.

Current velocity and discharge measurements during the second year of study (Table 5) were made with a Gurley current meter.

SECTION VI

RESULTS AND DISCUSSION

SPECIES COMPOSITION

A total of 83 macroinvertebrate taxa were collected from Piceance Creek and its tributaries during the study period (Appendix A). A list of diatom species collected in Piceance Creek is presented in Appendix B. Table 6 gives the common invertebrate taxa and their distributions in Piceance Creek.

Only two identified species, *Baetis tricaudatus* and *Simulium arcticum*, were common at all sites, which indicates the tolerance of these species to the widely varying physical and chemical conditions present, as well as the tendency for species of these genera to be active drift organisms (Waters, 1972). It is possible that several species of the chironomid genera *Eukiefferiella* and *Orthocladius*, were also widespread, but species designations were not possible.

The remaining taxa were more restricted in distribution. With few exceptions, *Capnia* spp. and *Glossosoma ventrale* were restricted to PC-1. *Ephemerella inermis* and *Isoperla patricia*, were more tolerant of increases in temperature, TDS, and siltation, and occurred throughout upper Piceance Creek and its tributaries.

The increased organic enrichment and siltation at the middle and lower Piceance sites was indicated by the abundance of the oligochaetes *Limnodrilus hoffmeisteri* and *Tubifex tubifex*. These in turn influenced the distribution of the leech *Helobdella stagnalis*, because oligochaetes are an important component of its food (Herrmann, 1970).

The only abundant taxa at the lower Piceance sites were those organisms widespread in Piceance Creek (tubificid oligochaetes, *Baetis* spp., and several chironomids), and two species found primarily at these sites, *Tricorythodes minutus* and *Ophiogomphus severus*. These latter species are adapted to highly silted conditions and are reportedly characteristic of warm, turbid streams in the West (Edmunds and Musser, 1960; Musser, 1960). *Tricorythodes* may, however, be found in cool, relatively silt-free streams if submerged angiosperms are present (Ward, 1974, 1976a).

In general, the fauna of Black Sulphur Creek was similar to the middle Piceance sites. However, it did have some taxa in common with PC-1 (*Brachycentrus americanus* and Diamesinae chironomids) and with the lower Piceance sites (other chironomids) which reflected its spring-fed nature and central location in the Piceance Creek watershed.

TABLE 6. DISTRIBUTION OF MAJOR TAXA IN PICEANCE CREEK, COLORADO, AUGUST 1975 TO JUNE 1976

Taxon	Sampling site		
	PC-1	PC-2 to PC-4	PC-5 to PC-7
Baetis tricaudatus	X	X	X
Ephemerella inermis	X	X	
Tricorythodes minutus		X	X
Isoperla patricia	X	X	
Capnia spp.	X*		
Hydropsyche oslari	X	X	
Glossosoma ventrale	X*		
Ophiogomphus severus			X*
Optioservus quadrimaculatus		X*	
Tipula commiscibilis	X	X	
Simulium arcticum	X	X	X
Tubificidae spp.		X	X

*Indicates species is restricted to site(s) indicated, with few exceptions.

The fauna of Willow Creek closely resembled that of Black Sulphur Creek and the middle Piceance sites. Stewart Gulch, however, had a much less varied fauna consisting primarily of *Baetis*, tubificids, and various dipterans.

DENSITY AND BIOMASS

The Piceance Creek sites showed considerable downstream decreases in density, biomass, and number of macroinvertebrate species which reflect the increasing severity of physical and chemical conditions (Table 7, Figure 3). Decreases between the upper (PC-1 to PC-4) and the lower sites (PC-5 to PC-7) were particularly evident. In order to determine which factors were the most important in causing this trend, it was necessary to examine seasonal changes at several sites.

Due to its stable flow and the abundance of winter-emerging species, density and biomass values at PC-1 were high during the winter (Figures 4 and 5). Fluctuations during this period were largely caused by recruitment and emergence in winter stonefly and Diamesinae chironomid populations. Values declined greatly in the spring from runoff scour and emergence. In early summer, densities increased gradually as typical summer species, such as *Simulium*, reappeared. Relatively large biomass values at this time resulted from the growth of *Glossosoma* and *Tipula* larvae. Values again declined at the time of the fall emergence.

The middle Piceance sites followed a trend similar to PC-1. However, this was the result of other factors, including reduced runoff scour, changes in algal populations, and more severe winter conditions.

At the middle Piceance sites, stream flow during spring runoff was reduced by irrigation withdrawals. This apparently accounts for the relatively high densities and biomass in the spring and early summer (Figures 4 and 5). The streambed was not greatly scoured, and macroinvertebrates displaced from headwater areas (catastrophic drift from both Piceance Creek and its tributaries) were able to find refuge. The reappearance of filamentous algal growths (*Cladophora*, *Enteromorpha*, and others) may also have contributed. These growths not only provide an important microhabitat for many organisms (chironomids, *Baetis*, *Hydroptila*, *Limnophora*, and early instars of many species), but can also serve as a trap for drifting organisms (Barber and Kevern, 1973).

The lowest density and biomass values at the middle Piceance sites occurred at the onset of winter when surface and frazil ice were formed and algal growths were lost. Unlike the lower Piceance sites, however, the general absence of anchor ice in mid-winter allowed populations to recover until spring emergence.

At the lower Piceance sites density and biomass trends were virtually identical with highest values in May, July, and October (Figures 4 and 5). The spring peak was caused by late instars of *Isoperla patricia* and *Ephemerella inermis* apparently as a result of drift from upstream. Values

TABLE 7. PICEANCE CREEK AND BLACK SULPHUR CREEK MACROINVERTEBRATE PARAMETERS (GRAND MEANS AND RANGES), AUGUST 1975 TO JULY 1976

Sampling site	Parameter				
	Density (indiv./m^2)	Biomass (g/m^2)	Total taxa	Diversity (range/median)	Equitability (range/median)
PC-1	3,534	24.3	25	1.76-3.11 2.63	0.22-0.49 0.35
PC-2	3,273	14.0	26	2.10-3.28 2.80	0.23-0.54 0.35
PC-3	3,192	15.2	25	2.25-3.40 2.92	0.28-0.66 0.50
PC-4	2,088	23.6	26	2.22-3.45 3.07	0.29-0.58 0.49
PC-5[a/]	1,328	5.7	16	1.13-3.21 2.57	0.29-0.80 0.50
PC-6[b/]	1,235	5.3	13	1.06-3.11 2.16	0.19-0.77 0.50
PC-7[b/]	509	2.4	13	2.10-3.22 2.14	0.34-0.95 0.40
BSC-1	2,962	17.0	23	1.59-3.87 2.78	0.20-0.89 0.34
SG-1	1,968	11.4	17	0.38-3.01 2.03	0.13-0.52 0.35
WC-1	1,032	15.2	16	1.58-2.74 2.11	0.25-0.50 0.36

[a/] Not sampled in August and January.

[b/] Not sampled in January and February.

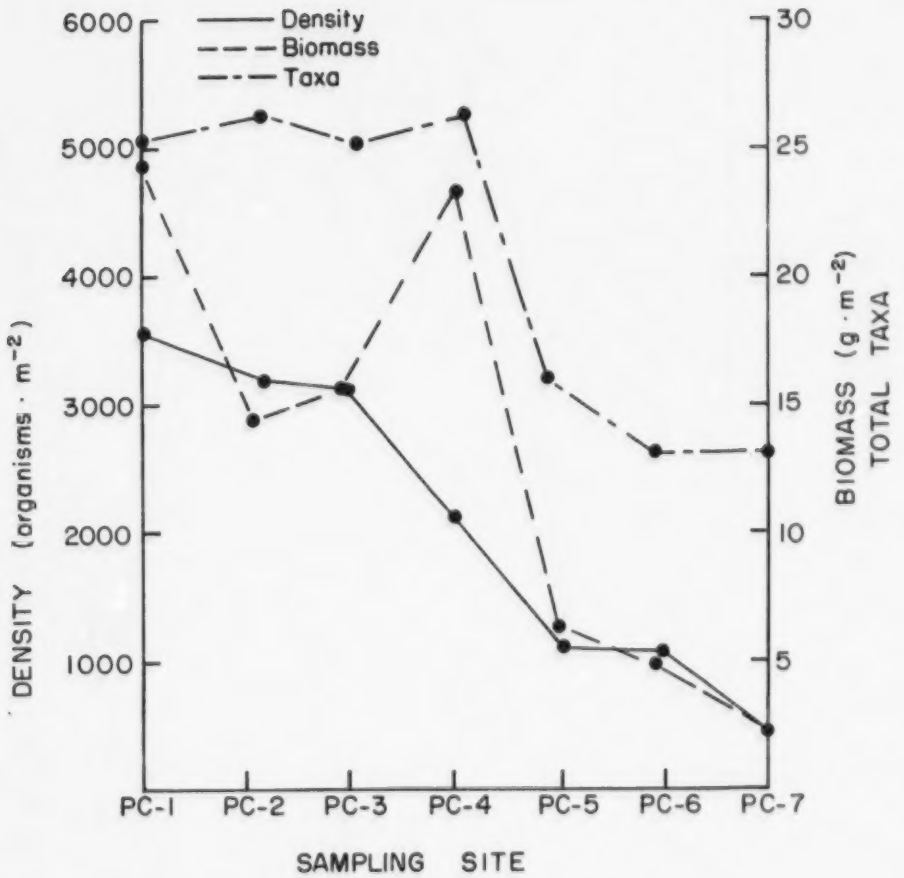

Figure 3. Mean density, biomass, and total number of taxa at Piceance Creek sampling sites, August 1975 to July 1976.

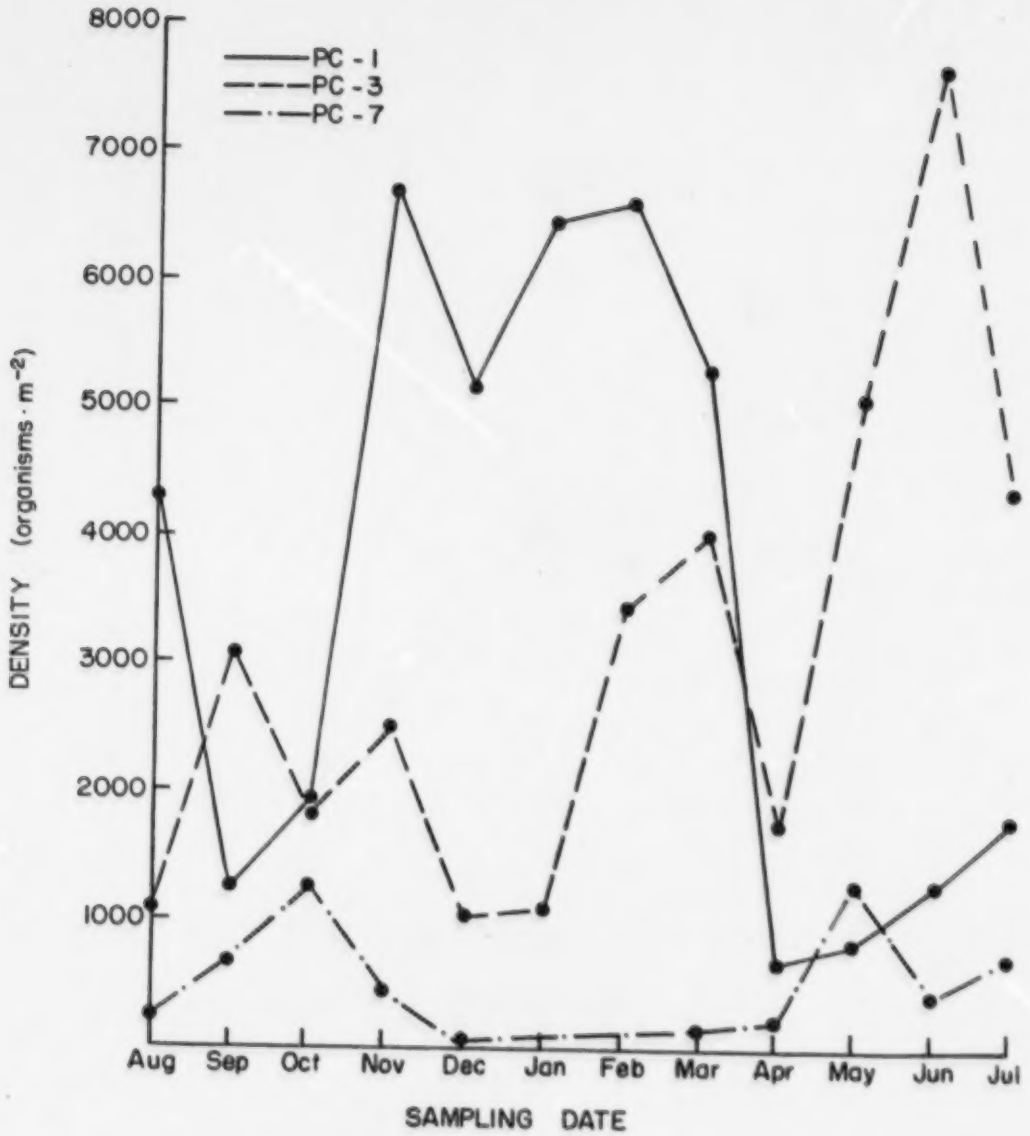

Figure 4. Total density at PC-1, PC-3, and PC-7, August 1975 to July 1976.

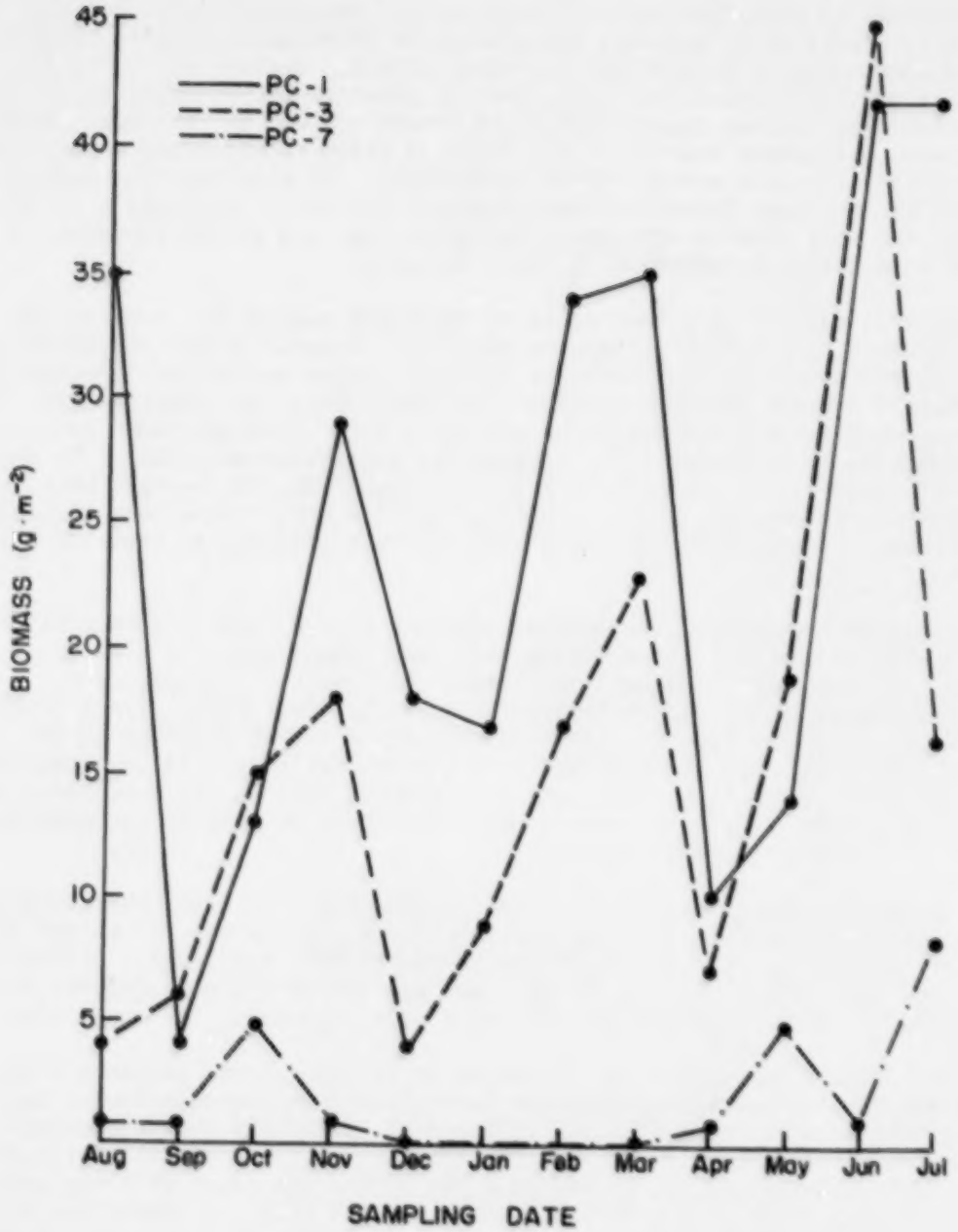

Figure 5. Total biomass at PC-1, PC-3, and PC-7, August 1975 to July 1976.

increased in the summer as characteristic species, *Tricorythodes minutus*, *Ophiogomphus severus*, and *Baetis insignificans*, reappeared in abundance. In the fall, growth of *O. severus*, recruitment of chironomids, and recruitment of the second mayfly generations increased values. Anchor ice during the winter almost eliminated the fauna, and its presence was an important factor in determining species composition. The common species at the lower Piceance sites were all summer species, i.e., those in which hatching and growth takes place during the warm months (April to October). In contrast, the common species of the upper Piceance sites (*Isoperla patricia*, *Ephemerella inermis*, *Tipula*, and many others) were those for which the cold months (November to March) were the most important in the life cycle.

Several factors have been noted as important reasons for the low density, biomass, and number of taxa at the lower Piceance sites. Of these factors, the data from PC-5 indicate that substratum was not as important as temperature regimes (including winter ice conditions), and physical and chemical conditions (high turbidity and salinity). PC-5 was added as a sampling site in September 1975, because its substratum was similar to the upper Piceance sites. Despite this greater stability, its overall macroinvertebrate values were nearly identical to PC-6 which has a more unstable substratum. In addition, its common species were the same as those at PC-6 and PC-7.

As noted previously, the common organisms at the lower Piceance sites are all summer species. In addition, most are rather small in size (e.g., *Baetis*, *Tricorythodes minutus*, tubificids, chironomids, and *Hydroptila*). This may be due to the higher temperatures at the lower sites, since smaller organisms are better able to withstand concurrent oxygen stresses (Hynes, 1970). There may also be an effect from current velocity. It is noteworthy that the only common large organism, *Ophiogomphus severus*, is a burrower and was found in the largest numbers in backwater areas or beds of *Zannichellia* where current velocity was reduced.

Macroinvertebrate values for Black Sulphur Creek were generally similar to the middle Piceance sites (Table 7). Density and biomass values for the smaller tributaries (Stewart Gulch and Willow Creek) were lower. Although densities were relatively low, biomass was not correspondingly reduced due to the abundance of large dipterans such as *Tipula*, *Hexatoma*, and *Limnophora*.

The percentage composition of the major taxa for three Piceance sites and Black Sulphur Creek are presented in Table 8. In Piceance Creek, downstream decreases in the relative importance of Plecoptera and Trichoptera and an increase in Oligochaeta are evident. Diptera values generally followed opposite trends for density and biomass due to the dominance of large species (e.g., *Tipula*) at upstream sites and small species (e.g., chironomids) at the lower sites. The higher percentages for Ephemeroptera at PC-3 result from three abundant species (*Baetis tricaudatus*, *B. insignificans*, and *Ephemerella inermis*), whereas PC1 and PC-7 had only one. Values for BSC-1 showed a dominance of dipterans as did Stewart Gulch and Willow Creek.

TABLE 8. PERCENTAGE COMPOSITION OF MAJOR TAXA AT PICEANCE CREEK AND BLACK SULPHUR CREEK SAMPLING SITES, AUGUST 1975 TO JULY 1976 (VALUES ROUNDED TO WHOLE NUMBERS)

Taxon	Sampling site							
	Density				Biomass			
	PC-1	PC-3	PC-7	BSC-1	PC-1	PC-3	PC-7	BSC-1
Ephemeroptera	26	44	19	32	7	24	8	15
Plecoptera	31	8	1	3	14	15	4	8
Trichoptera	17	5	2	3	13	11	4	7
Diptera	26	18	54	51	65	33	38	60
Subtotal	100	75	76	89	99	83	54	90
Oligochaeta	*	13	20	8	*	9	8	5
Total	100	88	96	97	99	92	62	95

*Less than 1%.

An overall average of 2,166 organisms with a biomass of 12.9 g per m^2 was found for the seven Piceance Creek sites in the first year of study. The mean biomass of 13.7 g/m^2 reported by Pennak (1974) for Piceance Creek corresponds closely to the standing crop found in the present study. This is much higher, however, than the mean value of 3.4 g/m^2 found by Everhart and May (1973), as interpolated from their tabulated data by Pennak. All studies have noted that considerable downstream decrease in macroinvertebrate standing crop and concurrent changes in species composition.

AUGUST 1976 TO APRIL 1977 STUDIES

Macroinvertebrate sampling during this period was designed to describe in greater detail the communities present at the middle Piceance Creek sites (PC-2, PC-3, and PC-4). In addition to riffle habitats at these sites, a pool habitat was also sampled at PC-4. This pool habitat was defined as an area with slower current speed, deeper water, and smaller substrate particles than riffle areas.

Macroinvertebrate parameters for this period are given in Table 9. Compared to the previous year's data, large increases are evident in both density and biomass values. Density values were larger due to increased numbers of tubificids, whereas biomass values increased from higher densities of both *Tipula* and tubificids. The majority of species present at these sites had comparable or slightly higher densities during the second nine months when compared to the first year. The only common species to decline in numbers was *Ephemerella inermis*. These changes probably result from reduced discharge during 1976-1977, because this would create and maintain larger areas of extensive siltation.

There was also much milder fall and winter weather during the second year. Although the seasonal cycles during the second year were similar to that illustrated for PC-3 in Figures 4 and 5, the decline in numbers at the onset of winter was much smaller.

The changes occurring at the middle sites are also illustrated in Table 10. The riffle site with the greatest discharge, PC-4, changed the least in composition from the first year to the second.

Although total densities at the three riffle sites were nearly equal during the second year, biomass values increased greatly downstream (Table 9). This increase was caused largely by the downstream increase in *Tipula* (Table 10). This large species is most abundant near spring sources, and its relative importance reflects the influence of Stewart Gulch on PC-3 and Willow Creek on PC-4. In addition to affecting temperature regimes, these tributaries may also be important refuges for several common species (e.g., *Baetis*, *Isoperla*, and *Hesperophylax*). As noted in the seasonal trends for PC-3 during the first year of study (Figures 4 and 5), there was a gradual recovery following the onset of severe winter conditions, and large increases in the spring presumably as a result of downstream drift. It is doubtful these events would have occurred unless there was considerable movement of organisms from the tributaries and headwaters.

TABLE 9. MACROINVERTEBRATE PARAMETERS (GRAND MEANS AND RANGES) FOR PC-2, PC-3, AND PC-4, AUGUST 1976 TO APRIL 1977

Parameter	Sampling site			
	PC-2	PC-3	PC-4R	PC-4P
Total density, number/m^2	4,924	5,168	5,154	1,871
Total biomass, g dry wt/m^2 (g wet wt/m^2)	3.95 (26.3)	5.18 (34.5)	6.70 (44.7)	0.82 (5.5)
Total taxa	24	25	26	13
Diversity range/median	0.84-3.38 2.84	1.80-3.28 2.38	2.60-3.53 3.14	1.10-3.36 1.26
Equitability range/median	0.14-0.53 0.40	0.20-0.49 0.28	0.37-0.65 0.48	0.24-0.74 0.26

TABLE 10. PERCENTAGE COMPOSITION OF MAJOR TAXA AT PC-2, PC-3, AND PC-4 (VALUES ROUNDED TO WHOLE NUMBERS)

Taxon	Density			Biomass			Density				Biomass			
	PC-2	PC-3	PC-4	PC-2	PC-3	PC-4	PC-2	PC-3	PC-4R	PC-4P	PC-2	PC-3	PC-4R	PC-4P
	August 1975 to July 1976						August 1976 to April 1977							
Ephemeroptera	36	44	46	23	24	8	30	25	39	10	10	6	7	4
Baetis spp.	26	35	34	--	--	--	22	23	35	8	5	5	6	4
E. inermis	9	7	9	--	--	--	8	2	2	2	4	1	1	*
Plecoptera (*I. patricia*)	2	8	15	4	15	19	7	4	6	1	10	6	6	2
Trichoptera	5	5	5	13	11	8	6	3	6	1	15	8	10	5
H. oslari	3	2	2	--	--	--	5	2	2	*	13	7	6	3
Diptera	16	18	18	36	33	60	12	13	18	27	29	44	59	47
T. commiscibilis	*	*	1	--	--	--	*	1	1	*	20	38	51	36
Coleoptera (*O. quadrimaculatus*)	5	7	7	1	3	1	4	5	5	*	3	2	1	1
Oligochaeta (Tubificidae)	34	13	4	19	9	2	40	47	21	59	28	26	4	35
Hirudinea (*H. stagnalis*)	2	2	1	3	4	1	1	2	3	1	2	3	3	3
Amphipoda (*G. lacustris*)	*	*	*	*	*	*	*	1	1	*	*	1	2	*
Total	100	97	96	99	99	99	100	100	99	99	97	96	92	97

*Less than 1%.

The pool habitat at PC-4 had relatively low density and biomass values compared to riffle areas (Table 9). Its unstable, silted, and often anaerobic substrate was inhabited primarily by tubificid oligochaetes and chironomids (Table 10). With the exception of *Baetis tricaudatus*, common riffle organisms, such as *Isoperla* and *Hydropsyche*, were rarely collected. Because pool areas comprised a considerable portion of the total stream habitat, conclusions regarding composition and standing crop of macroinvertebrates should not be based solely on samples from riffle areas.

SPECIES DIVERSITY AND EQUITABILITY

Medians and ranges of values for species diversity and equitability indices are given in Table 7. At the lower Piceance sites, median diversity values were smaller than upstream sites, and in addition, the range of values was generally greater, which is an indication of the greater physical and chemical fluctuations. However, the lower values at PC-1, compared to the middle Piceance sites, indicate that habitat stability can also lower diversity values. For example, thermal constancy eliminates species which require a wide range of temperatures to complete their life cycles (Ward, 1976b). Unlike the middle Piceance sites, relatively constant conditions at PC-1 allowed several species to become very abundant and dominate the community (e.g., *Simulium articum* in the summer and winter stoneflies).

Median equitability values at the Piceance sites were generally similar, although the range of values was much greater at the lower sites. Relatively low median values were found at PC-1 (see above) and PC-2 (due to large numbers of tubificids).

Diversity and equitability values for BSC-1 were similar to the upper Piceance sites. The wide range of equitability values was the result of abrupt changes in chironomid and simuliid populations. Low values for Stewart Gulch and Willow Creek are due to their spring-fed nature, and their relatively small size which reduces the diversity of microhabitats.

Values for PC-3 for the second year of study were lower than the first year because of an increase in tubificids (Table 9). Values for PC-2 and PC-4, however, were very similar. The pool habitat had very low diversity and equitability values.

STATISTICAL ANALYSES

Analysis of variance (F-distribution) were performed on density and biomass data for the Piceance Creek sites throughout the period of study. Following Elliott (1973), these data were first transformed to $\log_{10}$ before performing the analyses.

Transformation of the data was necessary in order to fulfill the requirement that variance be independent of the mean. With untransformed counts, the variance was always larger than and dependent on the mean. Although nonparametric tests, such as the Kruskal-Wallis one-way analysis by ranks, could be used instead, standard one- and two-way analysis of variance with

transformed counts has the advantage of allowing determination of the association of variance and determination of interaction.

In the first year of study, with density data from all seven Piceance Creek sampling sites, significant between-site variance ($p < 0.01$) was found for all dates except August 1975. No significant within-site variance was found. Significant variance ($p < 0.05$) between successive sampling dates was found for September-October, November-December, March-April, and April-May. These results reflect major periods of emergence and recruitment (fall and spring) and the onset of winter conditions. Significant site-date interaction ($p < 0.05$) was found for February-March, March-April, and May-June. The February-March interaction was caused by the large increase in tubificids at PC-2. Interactions in March-April (at PC-1, PC-2, and PC-3) and May-June (at PC-2, PC-3, and PC-4) resulted from changes in the densities of several species (particularly *Baetis tricaudatus*, *Ephemerella inermis*, *Isoperla patricia*, and *Simulium arcticum*) from emergence, recruitment, and drift.

Using biomass data, each Piceance site was compared with all other sites for the first year of study. All of the upper sites (PC-1 to PC-4) had significantly greater biomass ($p=0.05$) than all of the lower sites (PC-5 to PC-7). No significant variance was found within each group of sites. In the above analyses random error accounted for over 50% of the total variance.

In the second year of study, using density data from PC-2, PC-3, and PC-4 (riffle), no significant within-site variance was found. Significant between-site variance ($p=0.05$) occurred only for December 1976 which indicates the similarity in density values and seasonal trends at these sites. Significant variance between successive sampling dates ($p < 0.05$) was found for August-September, September-October, November-December, and March-April. These data indicate the similarity in seasonal trends for both study periods. Significant site-date interaction ($p \leq 0.05$) was found for August-September (at PC-3 and PC-4), November-December (at PC-2), January-February (at PC-3), and March-April (at PC-2). These interactions were caused by slightly different emergence periods of common species and severity of winter conditions at the three sites. Significant interaction at one site and not another may be more a function of sampling regime (i.e., monthly samples) than actual differences in the seasonal cycles.

Analysis of the biomass data for the second year showed no significant variation between the three sites (riffle areas). Significant variation ($p < 0.05$) was found between the riffle and pool areas at PC-4 for both biomass and density. As in the first year of study, random error accounted for over 50% of the total variance for all second-year analyses.

To compare the two types of samplers, an index of precision, D, was computed for several months of density data for each type. This index is defined as the ratio of the standard error to the arithmetic mean (Elliott, 1973). The median D value was 0.52 for the Surber sampler and 0.53 for the core sampler. The two samplers were nearly equal in precision, even though the core sampled only about one-third the area of the Surber. Although D values for both samplers are rather high, a reduction of this index to 0.20, for example, would require over 35 samples at each site.

Analyses were also performed using density and biomass data from the three middle Piceance sites in order to compare the two time periods: August 1975 to April 1976 and August 1976 to April 1977. Both density and biomass were significantly greater for the second period ($p < 0.001$), although random error accounted for over 60% of the total variance.

POTENTIAL EFFECTS OF OIL SHALE DEVELOPMENT ON PICEANCE CREEK MACROINVERTEBRATES

The main types of potential pollutants from oil shale development are: (a) sediments eroded from spent shale piles and areas of construction for access roads and mining facilities, (b) dissolved salts leached from spent shale piles, and possibly the entrance of groundwater with higher dissolved salt concentrations due to disturbances of the aquifer system, and (c) toxic trace substances leached from spent shale piles or released from an accidental spill. The effects of these potential pollutants would be influenced by possible alterations in flow rates in Piceance Creek from mine dewatering (changes in the aquifer system) and changes in topography (construction, deposition of spent shale, etc.).

Processing of oil shale results in very large quantities of waste shale. It has been estimated that each processing unit will produce 54,000 tons of waste shale per day. This waste shale will be backfilled into Sorghum Gulch (a small, usually dry tributary of Piceance Creek between Stewart Gulch and PC-3), compacted, and then revegetated. Eventually the spent shale pile will contain as much as 370 million tons of spent shale and cover about 400 to 500 ha (C-b Shale Oil Project, 1976).

Studies by Ward et al. (1971) and by Ward and Reinecke (1972) have shown that compacted spent shale is initially impermeable to water. However, snow cover eliminates this impermeability and allows leaching to occur. This leachate is very high in dissolved solids (up to 78,000 mg/liter) and contains several trace elements, particularly zinc, in biologically significant concentrations. Leachate from a spent shale pile would also contain suspended solids. Spent shale produced from the TOSCO II retort (the type of retort planned for use at tract C-b) is composed of small particles covered with residual organic carbon, and these particles would be capable of reacting with other substances, such as organic compounds and trace metal complexes (Grissinger and McDonald, 1970).

To control runoff from spent shale piles, a reservoir on Sorghum Gulch is planned (C-b Shale Oil Project, 1976). Water contained in this reservoir would either evaporate or be recycled for use in mining operations. Some water may also be discharged into Piceance Creek.

This reservoir would also be used for storage of water produced during mine dewatering operations. The extent of mine dewatering and its subsequent effects on the aquifer system of tract C-b, particularly with respect to [illegible]ring and surface flows, is unclear. According to Weeks et al. (1974) a [illegible]m stretch of Piceance Creek near tract C-b (including sampling sites PC-2, PC-3, and PC-4) would cease to receive groundwater discharge after 30 years of dewatering (the period of lease tract mining). Since groundwater

supplies 80% of the annual streamflow in Piceance Creek, such decreases would have significant effects on surface flows. However, studies reported in C-b Shale Oil Project (1976) indicated that much less water would be removed by mine dewatering than that predicted by Weeks et al. (1974), and in addition, consumptive losses would be decreased by recycling water held in storage.

Sediments carried in runoff will be contained in either the Sorghum Gulch reservoir or in small sedimentation ponds (C-b Shale Oil Project, 1976). At present, sediment yields for the Piceance Basin average 48 to 330 m^3/km^2 (Frickel et al., 1975). Estimates of yields for areas disturbed in the construction of mining facilities and additional access roads range from 950 to 1,900 m^3/km^2, whereas estimated yields from reclaimed overburden piles are 240 to 476 m^3/km^2.

The effects of mining will, of course, depend upon the types of extraction and processing employed and measures taken to protect the stream environment. Therefore, a discussion of their impacts on Piceance Creek macroinvertebrates will be general in nature with an attempt to relate them to present conditions and macroinvertebrate communities.

Increases in sedimentation (suspended solids) alter stream habitats in several important ways. They reduce the available habitat for macroinvertebrates by filling in interstitial areas (Gammon, 1970), and with continuous loading they can significantly reduce algal populations by inhibiting light penetration (Ellis, 1936). Macroinvertebrate communities developing on or in soft substrata show greater instability (Tebo, 1955), and populations can remain chronically suppressed under excessive sediment loads (Virginia Cooperative Fishery Unit, 1971). Additional effects could occur due to the special characteristics of the TOSCO spent shale. Upon entering the stream the sediment would be ingested by a number of macroinvertebrates. Any toxic materials carried on these sediments would then enter the food web and possibly be bioaccumulated through successive trophic levels.

Increases in dissolved salt concentrations increase osmotic stresses on macroinvertebrates, thereby increasing energy requirements for maintenance (Beadle, 1957). The high concentrations of salts at the lower Piceance sites are undoubtedly an important factor in limiting many species to upstream areas. It is notable that Odonata naiads, common at the lower sites, have been shown to possess special physiological mechanisms for coping with high osmotic pressures (Beadle, 1957).

Short-term releases of pollutants, such as accidental spills, could also have significant consequences. The seriousness of such an event would depend upon the substance, the location, and the time of release. The latter factor is particularly important. Fall (September and October) and spring (March to May) are major periods of emergence and recruitment for many species (Figures 3 and 4). The introduction of toxic substances during either period would reduce populations for at least one, if not more, generations.

The most important consequence of reductions in groundwater discharge near tract C-b would be an increase in temperature range, although reductions

would also have compounding effects by increasing sedimentation and concentrations of dissolved salts. Groundwater discharge has been previously noted as an important factor in preventing both high summer temperatures and anchor ice in winter at the middle Piceance sites. Ultimately, groundwater discharge reduction and its indirect effects would create physical and chemical conditions at the middle Piceance sites similar to those already present at the lower sites. The macroinvertebrate communities at the middle sites would change from one dominated by winter species (e.g., *Ephemerella inermis*, *Isoperla patricia*, and *Tipula*) to one composed of summer species (e.g., *Simulium arcticum*) and highly tolerant organisms (e.g., chironomids and oligochaetes).

If reductions in groundwater discharge were severe enough to completely dry up spring habitats for extended periods, a number of species (particularly *Tipula*, *Isoperla*, *Baetis*, and *Hesperophylax*) would be expected to decline in numbers in Piceance Creek. These spring habitats appear to serve as sources of organisms that recolonize Piceance Creek when its populations are depleted.

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APPENDIX A. TAXA COLLECTED FROM PICEANCE CREEK AND TRIBUTARIES, AUGUST 1975 TO APRIL 1977

INSECTA

Ephemeroptera

Baetidae
Baetis tricaudatus Dodds
Baetis insignificans McDunnough
Callibaetis sp.

Heptageniidae
Heptagenia sp. A
Heptagenia sp. B
Epeorus (Ironopsis) sp.

Leptophlebiidae
Paraleptophlebia sp.

Siphloneuridae
Ameletus sp.
Siphlonurus occidentalis Eaton

Ephemerellidae
Ephemerella inermis Eaton
Ephemerella grandis grandis Eaton

Tricorythidae
Tricorythodes minutus Traver

Plecoptera

Perlodidae
Isoperla patricia Frison
Isogenus colubrinus Hagen

Nemouridae
Prostoia besametsa (Ricker)
Zapada cinctipes (Banks)

Capniidae
Capnia logana Nebeker and Gaufin
Capnia gracilaria Claassen
Capnia confusa Claassen

Trichoptera

Hydropsychidae
Hydropsyche oslari (Banks)

Limnephilidae
Hesperophylax consimilis Banks

Brachycentridae
Brachycentrus americanus (Banks)

Glossosomatidae
Glossosoma ventrale Banks

Hydroptilidae
Hydroptila sp.

Odonata

Gomphidae
Ophiogomphus severus Hagen

Coenagrionidae
Amphiagrion sp.

Coleoptera

Dytiscidae
Deronectes depressus (Fabricius)
Agabus sp.
Laccophilus sp.
Oreodytes sp.

Elmidae
Optioservus quadrimaculatus Horn
Zaitzevia parvula Horn
Microcylloepus pusillus (LeConte)

APPENDIX A. Continued.

Coleoptera (Cont.)

Hydrophilidae
Enochrus sp.
Hydrobius sp.

Dryopidae
Helichus sp.

Haliplidae
Brychius sp.

Diptera

Tipulidae
Tipula commiscibilis Doane
Hexatoma sp.
Dicranota sp.
Pedicia sp.
Ormosia sp.

Culicidae
Chaoborus sp.

Dixidae
Dixa sp.

Psychodidae
Pericoma sp.

Ceratopogonidae
Palpomyia sp.

Simuliidae
Simulium arcticum Malloch

Tabanidae
Tabanus sp.

Rhagionidae
Atherix variegata Walker

Stratiomyiidae
Euparyphus sp.

Empididae
Chelifera sp.
Hemerodromia sp.

Diptera (Cont.)

Ephydridae
Ephydra sp.

Dolichopodidae
Unknown sp.

Anthomyiidae
Limnophora spp.

Chironomidae
Cricotopus sp.
Orthocladius sp.
Cardiocladius sp.
Eukiefferiella sp.
Psectrotanypus sp.
Procladius sp.
Micropsectra sp.
Tribelos sp.
Prodiamesa olivacea (Meigen)
Pseudodiamesa sp.
Diamesa sp.
Pentaneurini spp.

ANNELIDA

Oligochaeta

Lumbricidae
Eiseniella tetraedra (Savigny)

Tubificidae
Tubifex tubifex (O. F. Müller)
Limnodrilus hoffmeisteri Claparéde

Hirudinea

Glossiphoniidae
Helobdella stagnalis (L.)

CRUSTACEA

Amphipoda

Gammaridae
Gammarus lacustris Sars

APPENDIX A. Continued.

Isopoda

Asellidae
Asellus sp.

TRICLADIDA

Planariidae
Polycelis coronata (Girard)

NEMATODA

Mermithidae (?)

MOLLUSCA

Gastropoda

Physidae
Physa sp.

Gastropoda (Cont.)

Lymnaeidae
Lymnaea sp.

Planorbidae
Gyraulus sp.

Pelecypoda

Sphaeriidae
Pisidium sp.

HYDRACARINA

Limnocharidae
Limnochares sp.

Sperchonidae
Sperchon sp.

APPENDIX B. PICEANCE CREEK DIATOM SPECIES LIST

Division Bacillariophyta

Achnanthes lanceolata
Achnanthes minutissima
Cocconeis pediculus
Cocconeis placentula
Cymbella amphicephala
Cymbella minuta
Cymbella tumida
Denticula tenuis
Diatoma hiemale
Diatoma hiemale var. *mesodon*
Diatoma vulgare
Epithemia sorex
Fragilaria vaucheriae
Gomphonema olivaceum
Gomphonema parvulum
Meridion circulare
Navicula sp.
Navicula canalis
Navicula cryptocephala
Navicula exigua
Navicula pupula
Navicula radiosa
Navicula rhynchocephala
Navicula viridula
Nitzschia spp.
Nitzschia acicularis
Nitzschia amphibia
Nitzschia apiculata
Nitzschia dissipata
Nitzschia hungarica
Nitzschia linearis
Nitzschia palea
Pinnularia mesolepta
Surirella ovalis
Surirella ovata
Synedra ulna